INTEGRATION OF LANDSCAPE ECOSYSTEM CLASSIFICATION AND HISTORIC LAND RECORDS IN THE FRANCIS MARION NATIONAL FOREST

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Abstract—Geographic Information Systems (GIS) data and historical plats ranging from 1716 to 1894 in the Coastal Flatwoods Region of South Carolina were used to quantify changes on a temporal scale. Combining the historic plats and associated witness trees (trees marking the boundaries of historic plats) with an existing database of the soils and other attributes was the basis for exploring possible site types as defined by Landscape Ecosystem Classification (LEC) and historic vegetation.

Field plots were established using locations of the witness trees from the historic plats. The witness trees could then be used as a basis of comparison between past and present vegetation. From the field plots, four clusters of vegetation were delineated using Detrended Correspondence Analysis (DECORANA) and Two-way Indicator Species Analysis (TWINSPAN). Discriminant analysis revealed thickness of the A horizon, presence/absence of a B horizon, Landform Index (LI), and Terrain Shape Index (TSI) as discriminating variables in the model. These four site units revealed a soil moisture gradient ranging from very poorly drained soils to moderately well drained soils.

The historic witness tree data set was dominated by longleaf pine (70 percent). The comparison of historic witness trees to present vegetation showed a drastic decrease in longleaf across the landscape due to past management practices and the suppression of fire.

INTRODUCTION

The South Carolina Coastal Plain is home to some of the most biologically diverse ecosystems in the world. These ecosystems have been significantly altered by natural and anthropogenic activity over the past 10,000 years. Public pressures have prompted the United States Forest Service to manage National Forests as ecosystems (Brenner and Jordan 1991) having an array of uses and functions, rather than timber stands used only for the extraction of commodities.

An understanding of these ecosystems during presettlement times will prove to be invaluable for better management today. The objective of this study was to use Landscape Ecosystem Classification (LEC) and historical data to model presettlement (natural state) plant communities. This knowledge will assist in long-term studies of past ecological processes and provide a basis for the study of present modern day plant communities (Schafale and Harcombe 1982).

METHODS AND DATA ANALYSIS

Study Area

Field data were collected on 32 plots within Francis Marion National Forest (FMNF). These plots were located in areas of close proximity to locations of known witness trees from the historic plats. Witness tree data and the field plots encompassed some of the site units as defined by the Hilly Coastal Plain Province and Coastal Flatwoods Region LEC models for South Carolina Coastal Plain Province (Petitgout 1995).

Annual precipitation in the study area averages 47 inches and ranges from 39 to 55 inches. Summertime temperatures range from 65° to 90° F with temperatures in excess of 100° F occurring a few days most years. The average winter temperature is about 48° F with maximum and minimum temperatures of 60° and 35° F, respectively. The growing season is roughly 260 days (Long 1980).

Creating a Database

This project began with the creation of GIS (ARC/INFO) layers incorporating historic vegetation data and other cultural features from historic plats for areas in the FMNF. Fifty historic grant plats were initially acquired from the Charleston and Berkeley County records and digitized into the database, each as its own coverage (layer). These data were added to the already existing GIS database for FMNF. All of the vegetation, cultural features, and other relevant information were captured in the GIS. This information could then be used to perform spatial analyses and comparisons of the present vegetation and features in the FMNF versus the historic vegetation and features.

Sampling Procedures

In order to describe forest types in the areas defined by the witness trees, Landscape Ecosystem Classification (LEC) methodology was used to quantify vegetation and the underlying physical factors that help to discriminate among forest types. In preparation of going into the field, a map

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was created overlaying witness trees with the USFS forest type coverage using GIS. This map was used to identify mature stands (LEC calls for "steady-state") located in close proximity to the historic witness trees. Very few "steady-state" stands could be found throughout the FMNF, much less in the areas of witness trees where the study was restricted. This can be attributed to management practices and more so to the damage done to the forest by hurricane Hugo in 1989.

A circular 0.04 hectare plot was established in areas as delineated by witness tree data. Trees (no smaller than 4.5 inches diameter at breast height (dbh)), were measured for dbh and height for the entire 0.04 hectare plot. Seedlings, vines and herbaceous covers were sampled over the entire plot using a density class rating (Blanquet 1932/1951). Saplings (1-4 inches dbh) were tallied for a smaller subplot (0.01 hectare) in the center of the 0.04 hectare plot.

Soil samples were collected in three locations on each plot using a soil auger. Depth of the A and B horizons (C when there was no B) were determined in the field by averaging the three samples. Depth to maximum clay was also determined in the field. Maximum clay was a subjective measurement taken at the depth where the best ribbon could be made for the soil sample. No maximum clay was recorded for those soils determined in the field not to have B horizons. Soil samples from the A and B horizons (C horizon if no B existed) were composited for each plot. Texture analysis was performed in the lab, without the removal of organic matter, using the pipette method (Foth and others 1971).

Recent and ongoing studies in the southeastern Coastal Plain have shown that small differences in topography and landform can make a difference in the vegetative communities found and the site units derived (Stich 1994). For this reason, Terrain Shape Index (TSI) and Landform Index (LI) (McNab 1989, 1993) were recorded on each plot to determine the significance of these variables in distinguishing among site units.

Analytical Procedures

Vegetation data were summarized by species stratum for each plot. Relative density, relative basal area, and importance value 200 ((relative density + relative basal area / 2) x 100) were calculated by stratum for trees and saplings. Importance values were determined using relative frequency for seedlings, shrubs, and herbs. Where a single species occurred in more than one stratum, each instance was treated as a unique species or 'pseudospecies' (Carter 1994).

Detrended Correspondence Analysis (DECORANA) was the method of ordination used to analyze the vegetation data (Hill 1979a). TWINSPAN (Hill 1979b) was also used to analyze the vegetation data. DECORANA and TWINSPAN were used in the software package PCORD©. PCORD© is a windows based program used for multivariate analysis of ecological data (McCune and Mefford 1995).

Stepwise discriminant analysis and discriminant analysis (SAS 1990) were used to analyze the physical variables associated with the field plots. The soil variables used in the analysis were depth to maximum clay (inches), depth of soil horizon (inches), humus thickness (inches), and horizon texture. The landform variables used were Landform Index and Terrain Shape Index (McNab 1989, 1993). Stepwise discriminant analysis was used to determine the discriminating variables at the 0.20 significance level. The validity of the discriminant function was determined using resubstitution and cross-validation (SAS 1990).

Due to the small sample size of witness trees and dominance of longleaf pine in the sample, they were analyzed by looking at various relative frequency scenarios. The indicator or diagnostic species found in the ordination and classification were also compared to the witness trees and relative frequencies were observed. All of the basic statistics involving numbers of trees and area involved were conducting using GIS.

RESULTS AND DISCUSSION

Ordination and Cluster Analysis

The primary data matrix consisted of 32 plots and 307 species. A number of ordinations were performed to determine possible relationships between vegetation and the corresponding axes that represented a discernible environmental gradient. The first ordination was run using the exact groups delineated by TWINSPAN and then subsequent trials were performed in an attempt to achieve better classification and agreement between the ordination/ cluster analysis and the discriminant analysis. Personal judgement was used during group assignment based on knowledge of plot composition and characteristics.

Presence/absence data were analyzed for 32 plots and 307 species. DECORANA and TWINSPAN identified 4 groups. Axis 1 had a beta diversity of 3.8 standard deviations while axis 2 had a beta diversity of 4.3 standard deviations. A complete turnover in species should occur after 4 standard deviations along any of the axes (Hill and Gauch 1980). Numerous plots demonstrated disagreement in clustering by DECORANA and TWINSPAN. After studying the data closer, the clusters were modified. This was done systematically on a plot by plot basis and then rerunning the ordination as each cluster was altered by a single plot. Figure 1 represents the clusters that were the basis for the most accurate model using discriminant analysis.

Discriminant Analysis

Stepwise discriminant analyses were utilized to determine the significant physical variables that could be used to discriminate among the groups found using ordination and classification. Discriminating variables were identified and a linear model was created. Sixteen variables were entered during the stepwise discriminant analysis procedure. They were Landform Index (LI), Terrain Shape Index (TSI), root mat thickness (inches), depth to maximum clay (inches), A horizon thickness (inches), B horizon thickness (inches), presence/absence of a B horizon and relative proportions of sand, silt and clay in the A, B and C horizons. Five variables proved to be significant at the 0.20 level. These variables were (1) Landform Index (2) Terrain Shape Index

Table 1—Discriminant function equations of four ecological site units produced by discriminant analysis

Multiplier	Hydric	Mesic	Submesic	Intermediate
	Ecological Site Unit			
	Coefficient			
Constant	-17.48	-16.13	-5.64	-10.58
Landform Index	-77.05	143.33	53.42	-7.86
TSI	562.64	-2.23	298.33	530.98
B Horizon (Pres 1/Absence 0)	1.08	-0.30	0.41	1.37
A Horizon Thickness (inches)	1.19	0.27	0.55	0.61
Percent Sand (C)	-0.58	0.05	-0.22	-0.51

Table 2—Field model discriminant function equations of 4 ecological site units produced by discriminant analysis

Multiplier	Hydric	Mesic	Submesic	Intermediate
	Ecological Site Unit			
	Coefficient			
Constant	-12.17	-16.09	-4.9	-6.52
Landform Index	99.95	141.52	61.87	11.89
TSI	223.77	24.9	171.62	234.86
B Horizon (Pres 1/Absence 0)	-0.16	-0.20	-0.05	0.28
A Horizon (inches)	0.53	0.32	0.31	0.03

(3) thickness of the A horizon (4) presence/absence of B horizon and (5) percent sand in the C horizon.

Discriminant analysis was then used to determine how accurately these five significant physical variables could be used to classify the data into the four clusters delineated in figure 1. The discriminant function had a resubstitution classification rate of 88 percent and misclassified three plots. The cross-validation classification rate was 77 percent with seven plots misclassified. This represents the best model that could be created using all available data. The discriminant functions (model) for the initial run are in table 1. The correct site classification is the site unit with the highest sum of all the products of each site unit equation. In the discriminant model, a 1 represented the presence of a B horizon and a 0 represented the absence of a B horizon.

A second discriminant analysis procedure was performed to generate a model that could be used in the field. This field model was created using only those variables that were conducive to field measurement (table 2). Four of the five variables found to be significant (0.20) in the original stepwise discriminant analysis procedure were adequate for field sampling. These variables were (1) Landform Index (2) Terrain Shape Index (3) depth of the A horizon and (4) presence/absence of B horizon. The discriminant function had a classification success of 80 percent using resubstitution and 69 percent using cross-validation.

Axis Interpretation

The clusters found by DECORANA exhibited a moisture gradient across the landscape. The first axis in the ordination relates to a moisture gradient (figure 1). This can be seen in the vegetation but corresponding environmental and soil variables are difficult to interpret. Several studies have shown soil texture and depth to clay to be a surrogate for soil moisture (Marks and Harcombe 1981, Jones 1989) but no clear relationship can be seen here. There can be no doubt that the underlying factors affecting moisture on the sites are heavily correlated with soil texture and topography. However, the history of past land uses and disturbance in the study make it difficult to determine these relationships among the vegetation, soils, and landform.

Ecological Site Unit Descriptions

Each cluster defined by ordination/classification revealed a distinguishable group of vegetation and set of associated physical variables. This assemblage of species and physical variables forms the basis of the site units. Due to the wide range of sites sampled, the presence or lack of a B horizon was the most significant environmental variable discriminating among site units.

Hydric Site Unit

The hydric site unit is characterized by an overstory of swamp tupelo (*Nyssa biflora*) and pondcypress (*Taxodium ascendens*). Fetterbush (*Lyonia lucida*) and Virginia willow (*Itea virginica*) dominated the understory. There was no dominant herbaceous cover in the hydric site unit.

In the hydric site unit the B horizon thickness averaged 31.7 inches. The average A thickness was 14.9 inches. The average Landform Index (LI) was 0.14. The average TSI for the hydric plots was 0.01.

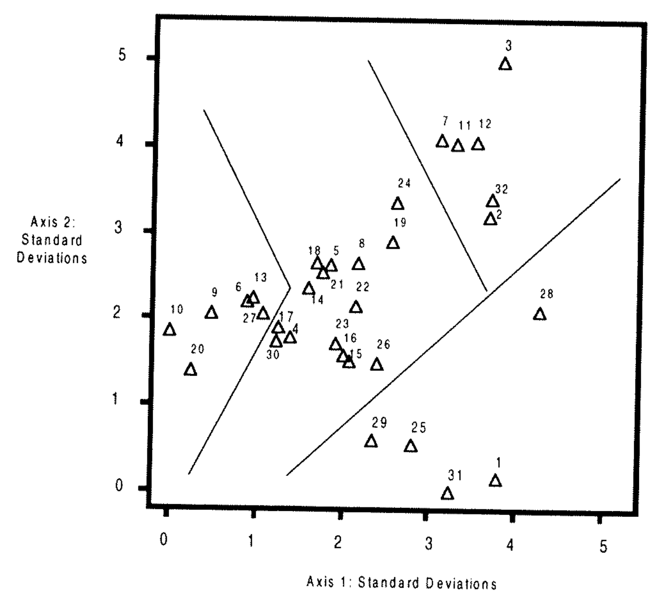

Figure 1—Presence/Absence Ordination of 32 plots and 307 species.

Mesic Site Unit

There was no overstory vegetation associated with the mesic site unit. The understory was dominated by the shrub American beauty-berry (*Callicarpa americana*) and flowering dogwood (*Cornus florida*) in the sapling stage. The herbaceous cover consisted of three vines: supplejack (*Berchemia scandens*), Virginia *creeper (Parthenocissus quinquefolia*) and variety of muscadine (*Vitis labrusca*).

Landform Index had a mean of 0.22 in the mesic site unit. The average Terrain Shape Index (TSI) was 0.007. The average A horizon thickness for the mesic site unit was 2.7 inches. The average B horizon thickness was 43.2 inches. There was no C horizon within the upper 50 inches of the soils in this site unit.

Submesic Site Unit

Tupelo (*Nyssa sylvatica*) dominated the overstory of the submesic site unit and Water oak (*Quercus nigra*) saplings characterized the understory. The herbaceous covers were predominantly red chokeberry (*Aronia arbutifolia*), and netted chain fern (*Woodwardia areolata*).

The submesic site units had an average A horizon thickness of 9.0 inches and an average B horizon of 34.0 inches. The average Landform Index was 0.1 and the average Terrain Shape Index was 0.01.

Intermediate Site Unit

The intermediate site unit had an overstory dominated by longleaf pine (*Pinus palustris)* and a shrub-like oak, running oak (*Quercus pumila*) characterized the understory. The herbaceous covers consisted of black-root (*Pterocaulon pycnostachyum)* and bracken fern (*Pteridium aquilinum).*

This site unit had an average C horizon thickness of 37.8 inches and 70.6 percent sand in the C horizon. The average A horizon thickness was 5.1 inches, there was no B horizon found in this site unit and Terrain Shape Index and Landform Index averaged 0.01 and 0.07, respectively.

Historic Witness Trees Associated with Field Plots

All historic witness trees located within 200 meters of the field plots were compared with the present day species occurring in the field plots. This portion of the analysis was accomplished using the GIS since none of the historic trees could be located on the ground.

Relative frequency of witness trees and present day trees was also examined. In the intermediate site unit, longleaf pine was represented in 100 percent of the plots by witness trees and present day trees. Tupelo (swamp or water tupelo) occurred in 25 percent of the intermediate site unit plots as a witness tree but did not occur in the present day field sampling.

In the sub-mesic site unit, Longleaf pine was represented on 87 percent of the plots by witness trees and 33 percent by present day trees. Pondcypress or baldcypress (*Taxodium distichum*) occurred 27 percent as a witness tree and 13 percent as a present day tree. Red maple (*Acer rubrum*) occurred only 6 percent as a witness tree but 60 percent as a present day tree. Blackgum was represented on 6 percent of the plots by witness trees and 47 percent of the plots by present day trees. As a witness tree, r. oak (red oak) occurred on 6 percent of the plots while oaks (in general) occurred on 100 percent of the plots as a present day tree. Bay (sweet bay (*Magnolia virginiana*)and beech (*Fagus grandifolia*)both had 6 percent occurrence as a witness tree in this site unit while they did not occur as a present day tree.

In the mesic site unit, longleaf pine as a witness tree occurred in every plot (100 percent) but did not occur as a present day tree. Water oak was represented by witness trees in 25 percent of the mesic site unit plots and 50 percent as a present day tree. Poplar (yellow-poplar (*Liriodendron tulipifera*)) occurred in 25 percent of the plots as a witness tree but did not occur as a present day tree.

In the hydric site unit, longleaf pine occurred 50 pecent as a witness tree and did not occur as a present day tree. Tupelo occurred 17 percent as a witness tree and 100 percent as a present day tree. P. oak (post oak (*Quercus stellata*)) and water oak (*Quercus nigra*) occurred 17 percent as witness trees but did not occur as present day trees in the hydric site unit.

DISCUSSION

Methodology used in plot location of this study differed from traditional LEC. To achieve accurate representation of the relationship between environmental variables and vegetation, LEC plots are located in areas with "steady-state" vegetation. Field plots in this study were positioned around the relative locations of known witness trees regardless of the state of the present day forest. For this reason, plots were distributed through a wide range of vegetation and sites that varied from dry, xeric uplands to standing water wetland areas. Since the determination of plots was based on the location of witness trees, some communities were excluded from the plots. For this reason, the classification may not necessarily represent a continuum in vegetative communities across all environmental gradients. It should be noted that none of the witness trees were located on the ground.

Four distinct vegetative communities were delineated occurring across a soil moisture gradient. These site units were found to reoccur on the landscape. Soil texture and terrain shape had significant influences on the moisture regimes across the landscape. Percent clay and depths to the clay were all discriminating variables in the site units delineated by discriminant analysis. This study demonstrated environmental variables that can be related to vegetation in areas of high disturbance such as the southeastern United States although they may not be the only factors at work shaping vegetation.

The incorporation of historical records into a GIS can greatly aid in spatially viewing past vegetation and land use. This was integral in mapping historic witness trees and the comparison of past and present day vegetation. The decrease in longleaf pine since the time of the historic records was the most apparent pattern.

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